

STUDIES ON THE COMPARATIVE HISTOLOGY
OF THE DIGESTIVE TUBE OF CERTAIN
TELEOST FISHES

by

Mary D. Rogick

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STUDIES ON THE COMPARATIVE HISTOLOGY OF THE DIGESTIVE TUBE OF CERTAIN TELEOST FISHES

II. A MINNOW (*CAMPOSTOMA ANOMALUM*)¹

MARY DORA ROGICK
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SIX FIGURES

AUTHOR'S ABSTRACT

This paper presents a study of the normal histology of the digestive tract of an herbivorous teleost, the minnow *Campostoma anomalum* (Rafinesque). The tunics of the buccal cavity, pharynx, esophagus, and intestine are described; particular attention is given to the mucosa because of the specializations occurring in that coat, such as taste buds, goblet cells, callous pad, etc. Because of the very decided anatomical and histological differences existing between the anterior and posterior regions of the pharynx, due to the presence of a callous pad and pharyngeal teeth, it has been deemed advisable to consider the pharynx as divisible into an anterior and a posterior region. Thyroid tissue was found in the submucosa of the anterior pharynx. No gastric epithelium was demonstrated, the 'intestinal bulb,' the only enlargement of the coelomic portion of the digestive tube, being lined with epithelium presenting only minor differences from that found in the coiled tubular intestine.

CONTENTS

Introductory	2
Buccal cavity	4
Buccal mucosa	4
Epithelium	4
Basement membrane	8
Stratum compactum	8
Buccal submucosa	9
Pharynx	9
Anterior pharyngeal mucosa	10
Epithelium of the roof	10
Epithelium of the floor	11
Basement membrane	11
Stratum compactum	11
Submucosa	11
Muscularis	12
Posterior pharyngeal mucosa	12
Epithelium of the roof	13
Epithelium of the floor	13
Basement membrane	14

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Submucosa	14
Muscularis	14
Esophagus	14
Mucosa	15
Epithelium	15
Basement membrane	17
Submucosa	17
Muscularis	17
Serosa	18
Intestine	18
Bulbar mucosa	19
Epithelium	19
Basement membrane	20
Submucosa	20
Muscularis	20
Serosa	21
Intestinal mucosa	21
Submucosa	22
Muscularis	22
Serosa	22
Summary	22
Conclusions	24
Bibliography	24

INTRODUCTORY

The present study is a description of the histology of the digestive tract of a minnow, the stone-roller, *Campostoma anomalum* (Rafinesque). This fish was chosen because of its uniqueness, being a representative of the almost entirely herbivorous genus, *Campostoma*. Some histological work has been done on the family Cyprinidae to which the stone-roller belongs, but little on *Campostoma*. According to Yung ('99), the following men have worked on the cyprinoid group, particularly on *Cyprinus carpio* and *Tinca vulgaris*: Bischoff ('38), Valatour ('61), Langer ('70), Waalewjin ('72), Biedermann ('75), Edinger ('77), Luchhau ('78), Garel ('79), Cattaneo ('86, '87), Decker ('87), and Oppel ('96).

The name of Pictet ('09), who also worked on *Cyprinus carpio* and *Tinca vulgaris*, as well as three other European species, may be added. Kraatz ('23) made a study of the food, and in 1924 published a paper on the intestine of the minnow or stone-roller, laying special stress on the development of the coiling. His work did not cover the anatomical

features of the mouth, pharynx, and esophagus. He noted, however, a simple columnar epithelium with goblet cells in the intestine.

In the author's study several specimens were used, one for anatomical, others for histological studies. Three had been fixed imperfectly in formalin, and the rest in Bouin's fluid; these last were the ones principally worked on. Preservation was in 80 per cent alcohol. The following stains were used: Delafield's haematoxylin, Heidenhain's iron-alum haematoxylin, eosin, methylene blue, and Mallory's triple connective-tissue stain. Of the last, both solutions were used on some sections, while only one solution was used on others. Sections were transverse, longitudinal, and occasionally tangential. The thickness varied from 2.5 to 10 μ , but the first made very unsatisfactory sections. In general, about 7.5 μ was the best thickness. The paraffin method was used throughout.

The writer wishes to express her appreciation to Dr. Irving H. Blake, of The University of Nebraska, under whose supervision the work was conducted, for encouragement and aid throughout the study; and also to Mr. R. K. Kinsey and his assistants, for assistance in the preparation of the fixatives and stains used.

The following parts of the digestive tract will be considered: buccal cavity, pharynx, esophagus, intestinal enlargement or bulb, and intestine proper. There is no true stomach in the stone-roller, but there is an anterior enlargement of the intestine, which corresponds in position to the stomach of other fishes.

The parts of the tract were measured in several adult specimens. In general, it was found that the length of the intestine alone was several times (up to more than six) the length of the body of the fish; this is in accordance with the work of Kraatz ('24). The following measurements are typical:

	<i>Cm.</i>
1. Buccal cavity,	.9
2. Anterior pharynx,	.6
3. Posterior pharynx,	.35
4. Esophagus,	.3
5. Intestinal bulb,	2.2
6. Intestine proper,	52.0

BUCCAL CAVITY

The buccal cavity extends from the lips to the first gill slit, or to the pharynx. It begins as a small, narrow cavity, roughly about 3 or 4 mm. wide, and quite rapidly widens, reaching its maximum width just at the anterior boundary of the pharynx. Roughly, it can be divided into the roof and the floor. There is little difference between the two regions other than that the floor contains the rudimentary tongue, and the roof a large triangular fold. The epithelium of both regions is lifted up in a series of low longitudinal folds, the folds being more pronounced at the sides of the cavity.

The following are the histological divisions of the mouth: a) mucosa (epithelium, basement membrane, and stratum compactum); b) submucosa.

Buccal mucosa

Epithelium. The epithelium of the buccal cavity possesses these elements: undifferentiated epithelial cells, cornified desquamating cells, mucous cells, and taste buds. Some of these elements are sharply localized.

The ordinary undifferentiated epithelial cells are present almost everywhere, around taste buds and mucous cells, as well as forming the basal layer of the epithelium. These cells, when crowded very little, have a regular, polygonal shape. They are found thus in the anterior mouth, as well as on the lips. In the posterior part of the mouth, this regularity of the cells is lost because of the great pressure of the goblet cells and taste buds. The definite cell outlines are also lost in the posterior part of the mouth; the nuclei, however, are in general smaller than those of the surface, and are more rounded. The cells at the surface, while still

typically regular, begin to show a slight tendency to flatten out (fig. 1).

The dead, desquamating cells are not common to all parts of the mouth. They are found only within the first millimeter of the buccal epithelium, being restricted to a median ventral and median dorsal zone. On each side of this zone, the ordinary buccal epithelium is present. This median zone is characterized by especially large polygonal epithelial cells,

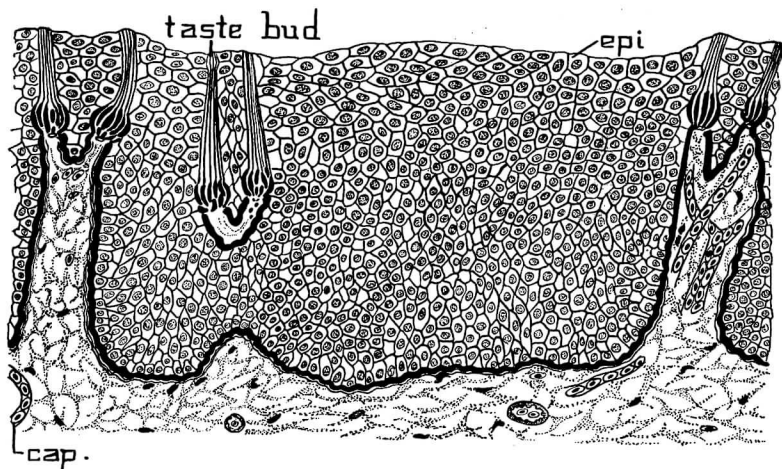


Fig. 1 This drawing of a transverse section of buccal mucosa and submucosa shows the type of tissue which is found on each side of the rudimentary tongue. Taste buds are present on the slender papillae of vascular submucosa. Capillaries (*cap.*) are seen in the vicinity of the taste buds. The epithelial cells are shown to be larger and differently oriented at the surface than at the base of the epithelium (*epi.*).

topped with the layer or two of dead cells. The dead cells are flattened, and lack the full, distinct nucleus of the underlying living cells. The cells below the desquamating layer have large nuclei and nucleoli. The basal portion of this region is marked in cross-section by a number of long, slender, finger-like projections of submucosa. These finger-like projections are lacking in longisection, the base of the epithelium appearing flat. This holds true for both the floor and the roof of the mouth. This type of epithelium is found in only

one other place in the alimentary tract—in the dorsal callous pad of the posterior pharynx. On the tip of the tongue, this structure is uniform in thickness and pierced by a number of thin, very evenly spaced submucosal folds. In the roof of the mouth this specialized epithelial structure can be divided into three zones—a median zone and two lateral zones, one on each side of the median zone. The lateral zones

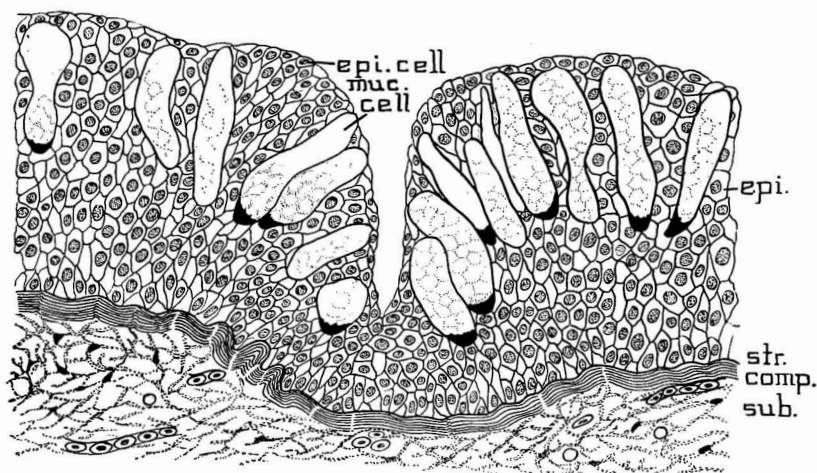


Fig. 2 Drawing of transverse section, showing epithelium, stratum compactum, and submucosa, taken posterior to figure 1. It shows the comparative size of undifferentiated epithelial and specialized mucous cells. A stratum compactum is shown in greater detail here than in the preceding drawing, appearing as a fibrous band rather than a solid black line. It has inconspicuous vertical interruptions. A very thin basement membrane underlies it. Capillaries are relatively common in the submucosa. *ep.*, epithelium; *epi.cell*, epithelial cell; *muc.cell*, mucous cell; *str.comp.*, stratum compactum; *sub.*, submucosa.

are considerably thinner than the thick median zone. The base of the three zones is pierced by numerous very thin longitudinal submucosal folds (fig. 3). This area corresponds roughly to the papillary region described by Pictet ('09) for *Tinca vulgaris*.

Mucous cells are present on and about the lips as well as in the digestive tract. Their number is somewhat limited in the anterior part of the mouth, but increases as one goes

posteriorly. No goblet cells were evident in the specialized epithelial structure corresponding to the papillary region of Pictet.

Behind this structure is found a fold which is transitional in the sense that it has epithelial cells of the undifferentiated type, goblet cells, and taste buds. Behind this fold the goblet cells and taste buds gain prominence. The goblet cells become

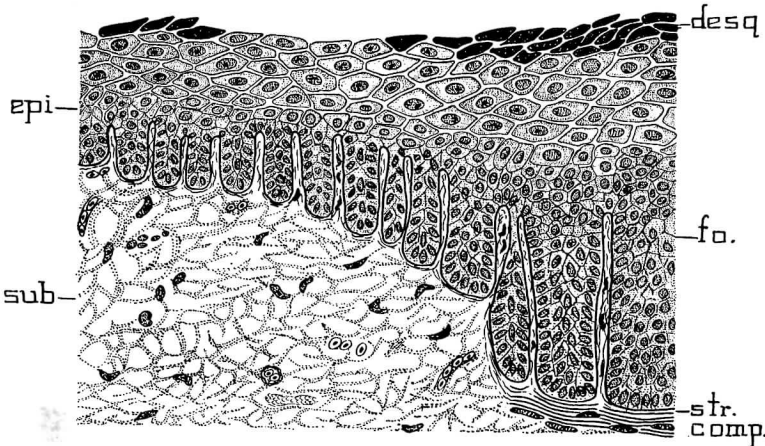


Fig. 3 Drawing of a transverse section of the somewhat calloused epithelial (*epi.*) structure of the first millimeter of the roof of the mouth. On the right is seen a part of the thick central zone and on the left, the thinner lateral zone with very large and regular epithelial cells. A surface layer of dead cells (*desq.*) is evident. Since this is a transverse section, it shows the uniform, narrow, longitudinal folds of submucosa (*sub.*) as finger-like projections into the epithelium. The stratum compactum (*str.comp.*) is quite thick under the central zone. *fo.*, folds.

so numerous that they give the outer half of the epithelium a blue color, while the basal half is yellow because of the number of epithelial cells; Mallory's stain brought this out very clearly.

Posterior to the transition zone may be found mucous cells which are somewhat atypical. Their nuclei, instead of being flattened at the base as is normally the case, are round. Also, they are found in a finger-like projection of the base of the cell. Their nucleoli stain very distinctly. The upper part

of the mucous cell is an enlarged sac, sometimes showing a reticular arrangement of the contents. Sometimes the number of mucous cells is so great that the epithelial cells are crowded away from the surface.

The organs (fig. 1) referred to both as sense and as taste buds (by Pictet) Herrick ('02) definitely states to be taste buds, even though found outside the body. In *Campostoma* they are flask-shaped. Pictet, in studying these organs in other species of Cyprinidae, found that there were two types of cells: the inner sensory cells and the outer enveloping nutritive cells. Both types, but the nutritive cells in particular, were characterized by elongate nuclei. In *Campostoma* the outer cells are so clearly arranged that the structure of the inner cells is difficult to determine. Moreover, the staining reaction of the nuclei of the outer cells is so intense that quite often the bulbous part of the taste bud appears as a dark mass of nuclei. The nuclei of the outer cells are long and narrow. The protoplasm of each outer cell is drawn out into a long narrow process reaching to the surface of the epithelium (fig. 1). The technique employed did not satisfactorily reveal the structure of the inner cells which were present.

The buds are quite plentiful about the lips, but not so numerous as in the anterior parts of the buccal cavity. They are a common element in the mucosa after the first millimeter of buccal epithelium. One very interesting fact about them is that they are always found on a slender finger-like papilla. Often two buds are present on the same papilla. Pictet, working on the tench and the carp, found three and even five buds resting on one papilla.

Basement membrane. A basement membrane, though somewhat hard to distinguish, is present as a thin fibrous sheet between the epithelium and the stratum compactum. It is blue when stained with Mallory's connective-tissue stain.

Stratum compactum. This layer is present in the mouth as a clear, wavy, uniformly staining band of fibers. In a few places, connective-tissue cells may be found between the fibers.

Buccal submucosa

Below the stratum compactum lies the submucosa, which is made up of rather fine strands of areolar connective tissue, capillaries, larger blood vessels, fat, and connective-tissue cells. As one goes away from the mouth, the fat cells increase in number, crowding the connective-tissue elements.

The premaxillary bones, underlying the submucosa, have many slightly wavy collagenous fibers about them, as well as numerous capillaries.

In the tip of the rudimentary tongue and in the lower lip is a membrane composed of large, uniform, very clear, stratified cells and traversed by many vertically directed collagenous fibers. In the tongue, this membrane is found to occupy most of the space in the submucosa.

The cone-shaped papillae on which the taste buds are borne are fairly numerous. In them are found capillaries, connective tissue, and nerve fibers. The technique employed did not differentiate the nervous elements, but the work on taste buds by others substantiates the statement.

PHARYNX

The division of the pharynx into an anterior and a posterior region is very marked, both anatomically and histologically. The anterior region extends from the first through the last gill slit; the posterior includes the region of the ventral pharyngeal teeth and a dorsal callous pad. These layers are present in the two divisions of the pharynx: a) mucosa (epithelium, basement membrane, and stratum compactum, the last in the anterior region only); b) submucosa, greatly reduced in the posterior region; c) muscularis.

The surface of the roof has a wrinkled appearance, and just in front of the callous pad of the posterior pharynx are a few short, flattened folds. The floor also has a few folds, but of a different type from the hardened ones of the roof. The amount of uninterrupted surface is greater in the roof than in the floor because the gill slits are lateroventral in position.

Anterior pharyngeal mucosa

The mucosa of the anterior pharynx consists of the following layers: epithelium, basement membrane, and stratum compactum.

Epithelium of the roof. The buccal epithelium continues into the pharynx. Large mucous cells make up the upper one-third to one-half of the thickness of the epithelium, while crowded, misshapen epithelial cells whose boundaries are very indistinct make up the rest. The mucous cells have a variety of shapes, being round, sacciform, finger-like, or a combination of these. Two features may be noted: first, the 'reticulate' effect produced by the mucus and, secondly, the type of nucleus, which is usually basal, but rounded rather than flattened against the base of the cell. A distinct nucleolus and a few coarse masses of chromatin material may be seen. Stratification of the cells is quite common except between the folds in some of the crypts.

A mass of discharged mucus may sometimes be seen on top of the epithelium and in the crypts, being often as thick as the epithelial layer itself. This condition was found in only a few sections, and may be due to poor fixation or to fixation during a certain stage of secretion. The mucous cells had broken down in some places, discharging their mucus into the colloidal mass referred to.

In the last millimeter, just in front of the dorsal callous pad, are a series of low, flattened folds, converging toward and terminating before the pad. Their crypts are of approximately the same width at top and bottom; they are lined with both mucous and ordinary epithelial cells, the former being found usually at the base. The mucous cells are not very plentiful at the top of the crypts. At the sides, they are localized, and may sometimes form a small secondary crypt. Elongate and somewhat spindle-shaped epithelial cells are almost as plentiful along the crypts as the goblet cells.

Taste buds are present in the roof, but appear to be more numerous in the floor and sides.

Epithelium of the floor. The floor is about three times wider at the first than at the last gill slit. The epithelium is usually thickest along the median line, thinning suddenly to a few layers of flattened epithelial cells at the gill slit.

The uniform, though somewhat flattened, epithelial cells appearing where there are few mucous cells readily fall into three divisions: the horizontally oriented surface cells, the vertical or oblique middle layer, and the basal division which is perpendicular to the stratum compactum. When taste buds and goblet cells are present, this arrangement is disturbed slightly.

The taste buds of the pharynx are like those of the buccal cavity. They are abundant, and are situated on top of the papillae of submucosa. The stratum compactum is very evident everywhere except just beneath the taste buds.

Basement membrane. A thin membrane is present just above the stratum compactum. The details of structure could not be made out.

Stratum compactum. The wavy, hyaline stratum compactum of the anterior pharynx is slightly thinner than that of the mouth. The underlying submucosa raises it up to form a number of papillae which bear taste buds. No invasion of the stratum by capillaries was noted here. Neither were the fibers of the stratum so apparent as in the buccal cavity.

Submucosa

The pharyngeal submucosa at first differs very little from that of the oral cavity, being areolar, very vascular, and heavily impregnated with fat. Posteriorly, the spaces between the fat cells become filled with striated muscle fasciculi. The increased amount of muscle finally reduces the submucosa to a narrow layer of connective tissue which is slightly deeper in the papillae. Just between the last pair of gill slits, this layer is thinned down to scattered connective-tissue cells and occasional fibers. Thyroid tissue was found in the submucosa of the anterior pharynx.

Muscularis

The amount of muscular tissue is not as great in the anterior as in the posterior region. It appears first in the form of longitudinal fasciculi at the base of the buccal submucosa and continues into the posterior pharynx. At first, there are a great number of fat cells, then between them begin to appear isolated and rather small fasciculi, some longitudinal and others transverse. Between the last pair of gill slits the muscle is separated from the stratum compactum by a very thin layer of submucosa. The muscle here is more compact, being in definite bundles. A change is very evident in the pharyngeal musculature between the first and last gill slits; the fat cells grow smaller, while the number of fasciculi about them is augmented. Numerous capillaries are present. The figure (fig. 5) shows a portion of pharyngeal tissues and is fairly typical of the region between the fourth and fifth gill slits.

The posterior pharynx is characterized by the following anatomical features: first, a flat, oval, callous pad, about 2.5×3.5 mm., occupying the roof; secondly, a wedge-shaped strip of mucosa on each side of the pad; and, thirdly, the paired inferior pharyngeal bones with their four pairs of teeth partially embedded in the ventral submucosa.

Sectioning of the floor is particularly difficult because of the pharyngeal teeth and bones. Removal of the hardened structures is equally difficult.

A macroscopic examination shows these parts: first, the flat, crescent-shaped stretch of epithelium supported by the pharyngeal bones; secondly, posterior to this crescent-shaped 'plateau,' a rough, longitudinal median ridge. On each side of this are four pharyngeal teeth alternating with transverse ridges of epithelium. The latter are higher than the teeth.

Posterior pharyngeal mucosa

The mucosa of the posterior pharynx differs from the regions anterior to it by the absence of the stratum compactum.

Epithelium of the roof. The extremely thick layer of desquamating cells on the pad stains a brilliant red with Mallory's triple stain. The top of the pad is narrower than the base, and the thickness is greater at the sides than at the middle. About twenty-five extremely slender submucosal folds penetrate halfway up the pad, being taller at the sides than at the center.

The cells of the pad are practically identical with those found at the tip of the tongue, being very large, polygonal, and oriented in the same manner. Very careful observation shows frequent intercellular cytoplasmic bridges.

In the anterior part are present a few short, wide taste buds within the epithelium.

On each side of the pad are a few low folds, their crypts lined with large sac-like mucous cells. Lateral to these are the wedge-shaped folds which differ markedly from the pad, possessing none of its large, polygonal, epithelial cells. No taste buds were visible, although several submucosal elevations were present. The tops of the folds were somewhat flattened. The stratification of slender, long, spindle-shaped epithelial cells results in a thick epithelium. Mucous cells are present, but desquamating cells are lacking.

Epithelium of the floor. The epithelium of the anterior pharynx gradually merges into that of the 'plateau,' thickening slightly. The epithelium is thickest at the point of termination of the 'plateau,' and is composed mainly of long, slender, almost cylindrical, stratified epithelial cells, the orientation of which is vertical except where disturbed by taste buds, mucous cells, or submucosal papillae. The plateau ends abruptly, giving way to tall folds, some of which branch. The crypts between them are lined with mucous cells from one to four layers deep. Unmodified epithelial cells are present at the base. Some of the highest folds have a number of epithelial and comparatively few mucous cells at the tip.

In one specimen the 'plateau' was covered by a fairly thick layer of flattened cells which had a curiously 'empty' appearance, being without nuclei. Some of these cells were

sloughing off into the pharyngeal cavity. They stained a pale blue with Mallory's stain. The surface layers of the corresponding dorsal region had the same peculiar appearance. The condition may have been due to poor fixation or other causes, since only one specimen showed the peculiarity.

Basement membrane. The fibrous elements of the submucosa which run up to the epithelium obscure the basement membrane, which is a very thin layer. A stratum compactum is absent from both the ventral and dorsal posterior pharynx.

Submucosa

The areolar tissue is invaded by numerous striated muscle fasciculi. The submucosa is thicker on each side of the pad than under it, because the muscle invasions are less heavy in the former place. A cross-section shows the pad resting on a very narrow strip of submucosa, with so many fasciculi that in a few places some of them press against the epithelium. The base of the pad is penetrated by a number of high, uniformly spaced, and very slender folds of submucosa.

Wherever a bone is found, there is some fibrous tissue. The bones themselves are not an element of the submucosa, but sometimes are found there, especially in the anterior pharynx.

Muscularis

The amount of submucosa is considerably limited by the invasion of both longitudinal and transverse striated fasciculi. Below this mixed zone is a band of connective tissue followed by transverse fasciculi, which in their turn are followed by longitudinal muscle. There are about five or six transverse bands separated by a strip of connective tissue. This is particularly evident in the dorsal pharynx. Fat cells are scarce, but capillaries are abundant around the fasciculi.

ESOPHAGUS

The esophagus is a small, uniformly thick tube about 3 mm. long. It is characterized by a large, anterior, longitudinal,

dorsal crypt or pocket which is bordered by folds on each side. In addition, there are about ten tall longitudinal folds between which are present two or three small folds. A pneumatic duct leading to the second chamber of the air bladder is a dorsal diverticulum of the esophagus. The four layers present in the esophagus are: *a*) mucosa, *b*) submucosa, *c*) muscularis, and *d*) serosa. A true stratum compactum is absent.

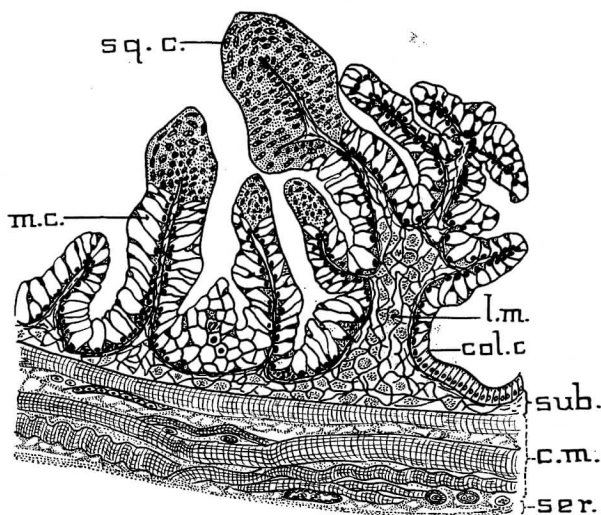


Fig. 4 This is a cross-section of the midesophagus, showing two major folds, their tips covered with stratified epithelium and their sides with mucous cells, a number of smaller folds, and on the right a small part of the dorsal crypt mentioned in the text. *col. c.* are the columnar cells which pass over into the lining of the pneumatic duct. The nuclei of these and the mucous cells are basal. Striated longitudinal fasciculi (*l. m.*) are found within the meshes of the fibrous submucosa (*sub.*). The circular muscle (*c. m.*) is just above the serosa (*ser.*).

Mucosa

Epithelium. In the anterior part the mucous cells are very numerous, but are rare at the entrance of the esophagus into the intestinal bulb. They line most of the large anterior dorsal crypt mentioned above. A small portion of this pocket is shown (fig. 4).

The ten or so major longitudinal folds are characterized by a thick layer of stratified epithelial cells covering their tips, and a number of large, distended mucous cells on the sides. Taste buds are present on some of the tips.

The smaller folds between the major ones do not show this differentiation. They are covered entirely with mucous cells, with the exception of some of the taller folds, which may

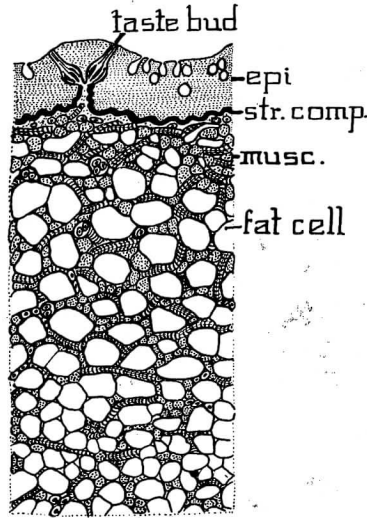


Fig. 5 Low-power drawing of section of anterior pharynx. The epithelium (*epi.*) has many squamous and fewer goblet cells. Two taste buds on one papilla are fairly common. A definite stratum compactum (*st.comp.*) is present, but the submucosa is reduced. The lower portion of the figure shows the great amount of fat present between the fasciculi.

occasionally have a small number of stratified epithelial cells at their tips.

The pneumatic duct, just at the point of departure from the esophagus, is characterized by clear columnar epithelial cells with basal nuclei.

The end of the esophagus is marked by a 'mixed' epithelium, showing the ordinary stratified epithelial cells and a new type, a single layer of cylindrical cells. The latter are rather wide columnar cells, staining an even color through-

out. Moreover, they do not show the tendency to shrink away from the neighboring cells, as do the taller, more slender, intestinal epithelial cells. The cylindrical cells are topped by a cuticular border or top-plate, while the ordinary stratified cells show no such structure. Various combinations of these cells may be found. Some of the folds may be formed of one type of cell and the base of the crypts of another, while other folds may have the simple epithelium on one side and the stratified on the other. Pictet mentions a slightly different type of mixed epithelium in four cyprinoids.

Basement membrane. A very thin basement membrane is present. A true stratum compactum is absent, although in places the submucosa is so fibrous and so close to the epithelium that it bears a very strong resemblance to this structure.

Submucosa

As in the pharynx, the submucosa is considerably reduced by the amount of invading muscle, but is thicker at the base of the folds and at the entrance of the esophagus into the intestine.

Muscularis

Striated muscle is the only type found in the esophagus. It forms a very thick coat. The dorsal wall, adjacent to where the pneumatic duct leaves the esophagus, is thin as compared with the ventral and lateral walls, and also shows a reversal of the muscle layers described below. Around the duct below the narrow submucosa is the inner circular muscle layer, and below that is the outer longitudinal one. A small amount of connective tissue separates the two.

The wall of the rest of the esophagus is considerably thicker. Longitudinal muscle is present in the meshes which are extensions of the fibrous submucosa. The fasciculi are separated from their neighbors by a space surrounded by a few collagenous fibers. Dawes ('29) found longitudinal fasciculi in the submucosa of the plaice. The outer, circular layer is more closely packed than the inner longitudinal, the fasciculi being closer together and in larger bundles.

The posterior boundary of the esophagus shows a very well-defined submucosa which is also invaded by small bands of striated circular muscle which increase in diameter and number as they approach the serosa. In this region the pneumatic duct is shown as a separate structure.

Serosa

The free part of the esophagus shows a fairly thick serosa, which is composed of connective tissue, capillaries, occasional larger blood vessels, and a surface layer of very flat peritoneal cells. The serosa of the esophagus is thicker than that of the intestine; this, however, may be due to the greater contraction of the former organ, especially in fixed material.

INTESTINE

A true stomach is absent in *Campostoma*, but its place is taken by an enlargement which for convenience has been designated as the intestinal bulb. Kraatz, in speaking of this region, calls it the 'swollen part of the intestine,' but makes no effort to make a definite division of it. The choledochal duct enters the posterior part of the enlargement. The long intestine behind the enlargement is nearly uniform in thickness. It is a very slender tube wound around the air bladder. Kraatz has made a very careful study of its coiling. The diameter of the posterior part of the intestine is somewhat smaller, especially near the anus. The intestine proper possesses the same tunics and almost the same cellular elements as the bulb.

The prominent zigzag folds of the mucosa can be seen readily through the semitransparent wall of the intestinal bulb. The height and complexity of the folds decrease as the tubular region of the intestine is reached. Uniformity in thickness characterizes the upper and lower parts of these folds, many of which unite, producing a branching effect in which the branches have the same width as the main fold. The turns formed by this branching or junction of folds are angular in the anterior part of the bulb. Toward the pos-

terior part, the angular folds have given way to less angular ones.

The following layers are found in both the bulb and the intestine proper: *a*) mucosa (epithelium, basement membrane); *b*) submucosa; *c*) muscularis; *d*) serosa.

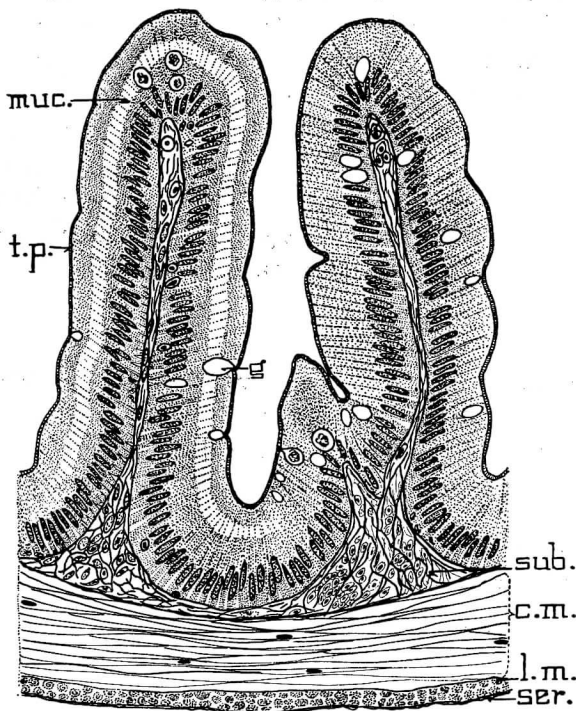


Fig. 6 A typical cross-section of intestine. *t.p.*, striated top-plate; *g.*, goblet cell; *muc.*, mucous (goblet) cells in an early stage of development; *sub.*, submucosa; *c.m.*, circular muscle; *l.m.*, longitudinal muscle; *ser.*, serosa.

Bulbar mucosa

Epithelium. The epithelium of the entire intestine, inclusive of the bulb, is simple columnar, the cells being very slender and tall, and resting on a very thin basement membrane, which in turn is supported by a thin sheet of submucosa. The nuclei of the cells are in the basal third, being slender, elongate, and possessed of fairly large masses of chromatin material.

Small wandering cells are quite common in the epithelium.

Mucous cells are not very numerous at first, but are more so in the posterior region. Nowhere in the intestine are they so plentiful as in the mouth, pharynx, and esophagus, nor do they present such a variety of shapes and sizes. The enlarged or mucus-filled portion of the intestinal mucous cell is spherical. The position of the enlargement varies; sometimes it is found at the base, and may occur anywhere between there and the top-plate.

No multicellular glands of the gastric or intestinal types were found anywhere in the bulb or intestine proper.

A distinctly striated top-plate covers the epithelium (fig. 6).

Basement membrane. A very thin basement membrane is present, but a stratum compactum is wanting.

Submucosa

The submucosa is present in every fold as a thin sheet of very vascular, fibrous connective tissue. It is thickest just at the bases of the folds. In general, it may be said that the submucosa does not form a very thick layer in the intestine or bulb.

Where the esophagus enters the bulb, the submucosa is much thicker than the submucosa of the rest of the bulb; the fibers are also finer.

Muscularis

Fasciculi of striated esophageal muscle continue for a short distance into the anterior part of the bulb. As they leave the esophagus, they are in several longitudinal and transverse layers, but finally are reduced to two: the inner circular or transverse, and the outer longitudinal layer. They still retain their striated character for approximately a third of the bulb, then give way to smooth-muscle fibers, which constitute the muscularis of the rest of the digestive tract. The circular layer is thicker than the longitudinal. The amount of connective tissue between them is usually small.

Serosa

Though there is some variation in the thickness of the serosa in different parts of the tube, it may be said that it is a very thin layer of characteristic simple squamous epithelium backed by connective tissue.

Diffuse pancreatic tissue surrounded with fat cells is found along the length of the entire intestine. The centro-alveolar cells and the zymogen granules of the pancreatic cells show plainly. Whether any pancreatic tissue is present in the liver was not determined, but will be investigated later.

The spleen (not previously described by Kraatz) is found in a loop of the middle intestine, where the loop rests on the large, left lobe of the liver. The dimensions of the spleen are:

	<i>Mm.</i>
Width,	2.5
Height,	3.0
Length,	5.0

There is no differentiation of the posterior part of the tract into the small and large intestine. The tube is uniform throughout, except in the last few millimeters, where it tapers slightly.

Intestinal mucosa

The intestinal epithelial folds decrease in height from anterior to posterior end. Those of the intestine proper are much smaller than those of the bulb; they also lack the complicated arrangement described for that organ. The angularity of the folds is lost, but the same elements are present in the two regions: numerous tall, slender epithelial cells, and comparatively few goblet cells.

In some preparations of both the bulb and the intestine, particularly those stained with haematoxylin, three regions are brought out in a layer of simple columnar epithelium. Under the striated top-plate is a fairly narrow band of darkly staining cytoplasm; next comes a thicker, lighter-colored layer resembling mucus; and lastly, the lower half of the cell containing the nucleus surrounded by cytoplasm similar to

that of the first layer (fig. 6). This appearance of the epithelial cells is due to the fact that they are changing into mucus-secreting cells; the mucus first appears somewhere in the middle of the cell and thence spreads to either the upper or lower zones.

The epithelial cells of the last few millimeters of the intestine, where the folds are very low, are slightly different from the cells of the anterior intestine. They are lower and not so slender. In this respect, they resemble the cylindrical cells described in the esophagus. Their nuclei have shifted from the basal part of the cell to the middle and have assumed a more oval shape.

A thin basement membrane underlies the epithelium.

Submucosa

The submucosa of the intestine is essentially the same as that found in the bulb, with the exception of the atypical region where the esophageal and bulbar submucosae meet.

Muscularis

Two layers of smooth muscle, an inner circular and an outer longitudinal one, are found in the intestine proper. The circular layer is slightly thicker than the other. The nuclei of the fibers are elongate and relatively small.

Serosa

In places, the serosa is extremely thin, but ordinarily it can readily be seen. It is a continuation of the serosa of the bulb.

SUMMARY

The buccal cavity is characterized by the presence of a rudimentary tongue, the anterior part of which resembles histologically the callous pad of the posterior pharynx. An area of the epithelium of the roof of the mouth just above the tongue shows a greater resemblance to the pad than does the tongue. On each side, and posterior to this specialized

area of epithelium, is found the typical buccal mucosa with its numerous mucous cells and taste buds. A basement membrane separates the epithelium from the very definite stratum compactum. A submucosa is present.

For convenience, the pharynx is divided into two regions: the anterior, being the region of gill slits; and the posterior, being the region of the dorsal callous pad and the ventral pharyngeal teeth. The callous pad is topped by a very thick surface layer of dead cells. The base of the pad is raised up by a number of submucosal folds simulating papillae when seen in cross-section. Taste buds and goblet cells are abundant in the anterior pharynx and less conspicuous in the posterior. The submucosa is present in both regions, but is greatly reduced by the invading pharyngeal muscles of the posterior part. Thyroid tissue was found in the submucosa of the anterior pharynx. A stratum compactum is present only in the anterior pharynx. The great amount of adipose tissue between the fasciculi leads to the peculiar appearance of the pharyngeal muscularis.

A dozen major folds, their tips covered with stratified epithelial cells, and their sides with distended goblet cells, characterize the esophagus. Goblet cells attain their greatest development here. Taste buds are present, but not in great numbers. A true stratum compactum is absent, although in places the arrangement of the adjacent connective tissue simulates this structure. The submucosa is limited by the invasion of striated longitudinal muscle, which is regarded as the first layer of muscle. The outer muscular layer is circular in direction. These layers are somewhat disarranged in the region where the pneumatic duct leaves the esophagus. The outermost coat of the esophagus is the comparatively thick serosa.

The transition from esophagus to the intestine is quite abrupt. The enlarged anterior part of the intestine has been designated as the intestinal bulb. The simple intestinal epithelium is composed of many long, slender columnar cells and less plentiful goblet cells, and is topped by a striated

cuticula. A submucosa, the fibers of which are very coarse, penetrates into every fold of mucosa. The anterior third of the bulb has a muscularis composed of striated fasciculi, which soon give way to two layers of smooth muscle: an inner circular and an outer longitudinal. The outer layer is the thin serosa.

CONCLUSIONS

The most striking histological features of the digestive tract of the minnow *Campostoma* are the following:

1. The presence of the callous pad of the posterior pharynx, with its thick, surface layer of dead cells, is not common to fishes in general.

2. A true stratum compactum is limited to the mouth and the anterior pharynx. Greene ('12) found a stratum compactum in the stomach, the intestine, and the pyloric caeca of the king salmon.

3. Taste buds are found as far down as the esophagus. They differ from a typical taste bud of higher forms such as man, in that they are flask-shaped and are located on the tip of a high submucosal papilla. They very frequently occur in pairs.

4. A true stomach is lacking, as shown by the absence of any multicellular gastric glands. The intestine is also of a very simple type, lacking multicellular glands. Their place seems to be taken by the mucous cells which are found in the entire tract.

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1. The first part of the report is a general
description of the project and its objectives.
2. The second part is a detailed description of the
methodology used in the study.
3. The third part is a description of the results
of the study.
4. The fourth part is a discussion of the results
and their implications.
5. The fifth part is a conclusion and a list of
references.

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